XXIV Physics in Collision - Boston, June 27-29, 2004

MEASUREMENT OF Z-QUARK, Z-ELECTRON COUPLINGS AND $\sin^2\theta_{\mathbf{W}}$ AT CDF

G. De Lentdecker, J. Lee, K. McFarland
University of Rochester, NY 14627-0171 USA
A. Gibson, G. Veramendi
UC Berkeley and LBNL
Y-K. Kim
University of Chicago / Berkeley
on behalf of the CDF Collaboration

ABSTRACT

The forward-backward charge asymmetry (A_{FB}) of $p\bar{p} \to e^+e^-X$ is sensitive to the vector and axial-vector couplings of the initial state quarks and final state leptons. Based on the measurement in 72 pb^{-1} of CDF Run II data, we measure the coupling constants of the Z boson to quarks and electron. The electroweak mixing angle, $\sin^2\theta_W$, is also measured through its relation to the coupling constants.

1 Introduction

This study is based on the measurement of the forward-backward charge asymmetry of electron-positron pairs at CDF in $p\bar{p}$ collisions with $\sqrt{s} = 1.96$ TeV at Fermilab [1]. The process $p\bar{p} \to l^+l^-$, where l is an isolated high P_T electron or muon, is mediated primarily by virtual photon at low energy [2], and by the Z at $M_{l^+l^-} = M_Z$. Elsewhere the interference of these two processes is an important effect. The vector and axial-vector couplings of the gauge bosons to fermions give rise to an asymmetry in the polar angle of the lepton momentum in the rest frame of the lepton pair with respect to the proton direction. The annihilation process $f\bar{f} \to e^+e^-$ depends on the helicities of the initial fermion f and the final electron e^-. The amplitude is given by [3]:

$$A_{ij} = A(f_i\bar{f} \to e^+e^-_j) = -Qe^2 + \frac{\hat{s}}{\hat{s} - M_Z^2 + iM_Z\Gamma_Z} C_i^Z(f)C_j^Z(e), \tag{1}$$

	Fermion					
	u quark		d quark		Electron	
Boson	C_L	C_R	C_L	C_R	C_L	C_R
γ	$2e/3$	$2e/3$	$-e/3$	$-e/3$	$-e$	$-e$
Z	$g_Z(-\frac{1}{2}+\frac{2}{3}x)$	$g_Z(\frac{2}{3}x)$	$g_Z(\frac{1}{2}-\frac{1}{3}x)$	$g_Z(-\frac{1}{3}x)$	$g_Z(\frac{1}{2}-x)$	$g_Z(-x)$

Table 1: Left- and right-handed couplings, where $g_Z \equiv \frac{e^2}{x(1-x)}$ and $x \equiv \sin^2\theta_W$.

where $\hat{s}$ denotes the square of the center of mass energy, and the coefficients are given in Table 1 for $(i,j) = (L,R)$. The differential cross section for $f\bar{f} \to e^+e^-$ is

$$\frac{d\hat{\sigma}(f\bar{f} \to e^+e^-)}{d\cos\theta^*} = \frac{\pi\alpha^2}{8\hat{s}}[(|A_{LL}|^2+|A_{RR}|^2)(1+\cos\theta^*)^2+(|A_{LR}|^2+|A_{RL}|^2)(1-\cos\theta^*)^2]. \tag{2}$$

The forward-backward asymmetry is directly calculated from the cross section.

$$A_{FB} \equiv \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4}\frac{|A_{LL}|^2 + |A_{RR}|^2 - |A_{LR}|^2 - |A_{RL}|^2}{|A_{LL}|^2 + |A_{RR}|^2 + |A_{LR}|^2 + |A_{RL}|^2}. \tag{3}$$

The forward-backward asymmetry (A_{FB}) is therefore a direct probe of the relative strength of the vector and axial-vector couplings between the Z and the leptons. The variations of the contributing helicities with $\hat{s}$ and of the up and down quark pdfs with x and thus $\hat{s}$ mean that individual chiral couplings of u and d type quarks can be found from A_{FB} over a range of M_{ee}.

2 Strategy

The values of the parameters are found by fitting the masurements of A_{FB} in fifteen dielectron invariant mass regions using 72 pb^{-1} of CDF Run II data [1]. The theoretical calculation uses ZGRAD [4], a Monte Carlo cross section calculation program for Drell-Yan dielectron and dimuon production with $\mathcal{O}(\alpha)$ electroweak corrections.

To fit for Z-quark coupling constants, the couplings between Z and $\mathsf{u_L}$, $\mathsf{u_R}$, $\mathsf{d_L}$, and $\mathsf{d_R}$ were allowed to change, while all the other parameters in ZGRAD were fixed to the Standard Model values. Table 2 shows the quark coupling values extracted from the best fit, together with the results from other experiments. The dominant source of the systematic error is the energy resolution of CDF electromagnetic calorimeter, which is measured using the rate of e^+e^- as a function of M_{ee}. Other sources of the systematic error include the uncertainties in PDF, the effect of material, energy scale and background. The coupling constants of the Z to left- and right-handed electrons are measured assuming Standard Model quark couplings

(1)		CDF ± stat ± sys	PDG	SM prediction
	u_L	0.413±0.141±0.061	0.330±0.016	0.3459±0.0002
	u_R	0.006±0.117±0.050	$-0.176^{+0.011}_{-0.006}$	0.1550±0.0001
	d_L	-0.318±0.204±0.039	-0.439±0.011	0.4291±0.0002
	d_R	-0.022±0.370±0.069	$-0.023^{+0.070}_{-0.047}$	0.0776
(2)		CDF ± stat ± sys	SLD + LEP	SM prediction
	e_V	-0.056±0.012±0.013	-0.03816±0.00047	-0.0397±0.0003
	e_A	-0.536±0.122±0.145	-0.50111±0.00035	-0.5064±0.0001
(3)		CDF ± stat ± sys	NuTeV [5]	LEP EWWG
	$\sin^2\theta_W$	0.2238±0.0046±0.0020	0.2364±0.0016	0.23143±0.00015

Table 2: Measurements of (1) Left- and right-handed quark couplings with Z, (2) Left- and right-handed electron couplings with Z, (3) effective $\sin^2\theta_W$.

and are also shown in Table 2. Finally, effective $\sin^2\theta_W$ is measured *via* its effects on the quark and electron couplings as in Table 2. The sensitivity is dominated by the Z-electron couplings near the Z pole.

3 Conclusion

The value of $\sin^2\theta_W$ and the coupling constants of quarks and electron to the Z boson were measured using 72 pb^{-1} of CDF Run II data. The result shows agreement with Standard Model. Since the errors are dominated by the statistical errors, sensitivity is expected to improve with higher luminosity, and systematic errors will improve with increased statistics.

References

1. Greg Veramendi *et al*, Measurement of Forward-Backward Charge Asymmetry of Electron-Positron Pairs, to be submitted to PRD.

2. S.D. Drell and T.-M. Yan, Phys Rev. Lett. **25**, 316, 902 (E) 1970; Ann. Phys. (N.Y.) **66**, 578 (1971).

3. J.L. Rosner, Phys. Lett. B **221**, 85 (1989).

4. U. Baur, O. Brein, W. Hollik, C. Schappacher and D. Wackeroth, Phys. Rev. D **65** 033007 (2002).

5. J. Erler, private communication; hep-ph/0005084.